Characterization of the Sun Drying Of Meat Slices in the Form of Kilishi with the Consideration of Surface Shrinkage

Aboubacar CHAIBOU AOUTA[1] Haoua AMADOU[2] Eloi Salmwendé TIENDREBEOGO[3]
[1,2]Laboratoire d'Energétique, d'Electronique, d'Electrotechnique, d'Automatique et d'Informatique Industrielle (L3E2I), Université Abdou Moumouni, Niamey, Niger
[1,2]Laboratoire d'Informatique Fondamentale et Appliquée-Sciences de l'Ingénieur, Université Abdou Moumouni, Niamey, Niger
[3]Laboratoire de Physique et de Chimie de l'Environnement (LPCE), Université Joseph Ki-Zerbo, Ouagadougou, Burkina Fasoa

Abstract— The drying of slices of meat, like almost all agri-food products, causes enormous variations in their physico-chemical and structural properties. In order to facilitate studies on the mechanism of drying, several authors in the literature attempt to neglect the shrinkage of the product, but the best results of studies on the mechanism of drying are obtained taking into account the shrinkage. In this article, the objective of our work is to make a characterization study of the sun drying of meat slices in the form of kilishi taking into account surface shrinkage. The methodological approach consists in evaluating during sun drying, the loss of mass and the shrinkage of the surface of the slices of meat using respectively an electronic scale and a double graduated decimeter. This process is repeated under different experimental tests. Using the experimental data obtained, we determined on the one hand, the curves of the surface shrinkage of the meat slices, the curves of the drying kinetics and the curves of the corrected drying kinetics. On the other hand, we determined the linear model of the surface shrinkage curve of the product, the polynomial model of the degree 4 drying characteristic curve and validated these models with a control experimental test. The relative errors between the two results are determined by the statistical parameters R2, MSE and RMSE. Examination of the values of these parameters obtained shows R2 is close to 1, MSE and RMSE are low values close to 0. This allowed us to conclude that the models are satisfactory.

Keywords: Surface Shrinkage Curve, Drying Kinetics, Corrected Drying Kinetics, Characteristic Drying Curve

I. INTRODUCTION

Drying food products is a very complex process that involves simultaneous transfers of mass and heat accompanied by variations in properties physico-chemical and structural of the product [1]. This then undergoes enormous modifications geometric patterns that should be taken into account in modeling drying and in establishing experimental drying curves Many authors have presented models for explaining the drying mechanism and the volume shrinkage of the product. We have as examples Lozano, Rostein & Urbicain [2] propose that the pores naturally open towards the outside are closed at low water contents. Suzuki, Kubota, Hasegawa & Hosaka [3] consider the material as a succession of cells in which is enclosed the liquid which diffuses towards the dry periphery. These studies which we have just cited propose a so-called fundamental shrinkage modeling method. It is based on a physical interpretation of the mechanism of the volume shrinkage of the product. It makes it possible to predict the geometric modifications of the product from the laws of conservation of volume and material. The method we used in this study is called empirical. It consists of adjust the experimental data using empirical models expressing the shrinkage as depending on the water content of the product. This is the case with the models used by Javier, Gabas & Paulo [4] for the mango; Al-Muhtaseb, MC Minn & Magee [5] for the potato; Hatamipour & Mowla [6] for the carrot; Ratti [7] for the potato. In addition in this work, the drying kinetics were determined and corrected taking into account the surface shrinkage of the meat slices. The linear model of the surface shrinkage curve of the product and the polynomial model of the degree 4 drying characteristic curve are validated by a control experimental test.

II. MATERIALS AND METHODS

A. *Experimentation*

1) *Preparation of the Product*

The fresh meat used in this study is cut into thin strips by a specialist in kilishi production. Before cutting the meat into slices; we apply the trimming which consists in ridding the meat of all the impurities (tendons, aponeuroses and fatty matter) which surround it. The meat obtained after the trimming operation is cut into large pieces and then into thin strips of slices a few millimeters thick.

2) *Equipment used*

The main equipment used for the drying operation are:

- A drying table and mat made from millet stalks, which are used to spread the product during the drying process;
- An electronic balance (PRECISA-205 A), precision 10-3 g, which is used for weighing the product;
- A double graduated decimeter used to estimate the length and width of the product during the drying process;
- A laboratory oven (PROLABO), which is used to determine the dry mass of the product.

a b c

Fig. 1: Main equipment used (a: double graduated decimeter, b: electronic balance and c: laboratory oven)

3) Measurement protocol

The thin strips of meat obtained are cut into rectangular slices of respective length and width of 15.19 cm and 7.50 cm. They are weighed before being spread out on a mat for the drying operation. They are continuously weighed and measured in length and width every 30 minutes until the end of drying. The dried meat slices are placed in an oven at 105 ° C. for 24 hours. The experimentally determined values of the water content on a dry basis are calculated by the following relation [8]:

$$X = \frac{m_{(t)} - m_s}{m_s} \tag{1}$$

With $m_{(t)}$, m_s and X respectively the mass in function time, the mass of the dry product and the water content in function of time

The average area of the meat slice sample at each point of drying is evaluated by the product of length and width assuming that the shrinkage is uniform.

$$S = L * l \tag{2}$$

With L, l and S respectively length, width and surface of the product.

The shrinkage curve is given by [1,9]:

$$\frac{S}{S_o} = f\left(\frac{X}{X_o}\right) \tag{3}$$

With S_o and X_o respectively the surface and the initial water content of the product.

The drying tests aimed at apprehending the surface shrinkage and the drying kinetics of the meat slices were carried out on six samples of relatively equal surface. These tests were repeated three (3) times during respective independent days: 06/16/2020, 06/25/2020 and 07/072020. The choice of these days is made at random on the best drying conditions (sunny day and low relative humidity).

B. Theoretical Models

1) Theoretical Model of the Product Surface Shrinkage Curve

This model results from the hypothesis of the additivity of the volumes of water and solids in assuming that the air volumes in the pores are negligible and the cell tissues are incompressible [1]. This hypothesis has already been used by many authors: Kilpatrick, Lowe, & Van Ardsel (1955) [10], Desmorieux (1992) [11], Iglesias Garcia, Roques, & Bueno (1993) [12], Leonardo & Dermeval (2004) [13] etc.

At a given moment of drying, if V denotes the total volume of the product, V_{dry} and Vw respectively the volumes of dry matter and water within the product,

$$V = Vw + V_{dry} \tag{4}$$

By expressing V as a function of the water content X of the product, we obtain [1]:

$$V = V_{dry}\left(1 + \frac{\rho_{is}}{\rho_{iw}} X\right) \tag{5}$$

With respectively ρ_{is} and ρ_{ie} the intrinsic density of the solid phase and that of the water of the product.

If V_0 is the initial total volume of the sample, it can be expressed by:

$$V_0 = V_{dry}\left(1 + \frac{\rho_{is}}{\rho_{iw}} X_0\right) \tag{6}$$

The volume shrinkage rate S_v is then expressed by:

$$S_v = \frac{V}{V_0} = \frac{1 + uX}{1 + uX_0} \tag{7}$$

With u is the coefficient of linear shrinkage given by:

$$u = \frac{\rho_{is}}{\rho_{iw}} \tag{8}$$

Assuming the shrinkage is isotropic and we neglect the variation in thickness. The surface shrinkage rate is given by:

$$S_s = \frac{S}{S_0} = \frac{1 + uX}{1 + uX_0} \tag{9}$$

By transforming equation (9), we get:

$$S_s = \frac{S}{S_0} = \frac{1}{1 + uX_0} + \frac{uX_0}{1 + uX_0}\left(\frac{X}{X_0}\right) \tag{10}$$

This relation assumes that the shrinkage varies linearly with the water content under the shape:

$$S_s = a + b\left(\frac{X}{X_0}\right) \tag{11}$$

With

$$a = \frac{1}{1 + uX_0} \quad \text{et } b = \frac{uX_0}{1 + uX_0} \tag{12}$$

2) Theoretical Drying Characteristic Curve Model

To describe the drying kinetics of slices of meat, we have used the principle of the characteristic drying curve. The principle of the method is developed by VAN MEEL [14]. The determination of the drying characteristic curve corresponds to the expression of the variation of a reduced drying speed as a function of a reduced water content [15]. Thus, we are therefore looking for an expression of the type [16]:

$$\frac{-\frac{dX}{dt}}{\left(-\frac{dX}{dt}\right)_0} = f(Xr) \tag{13}$$

With,

The drying speed at time t:

$$-\frac{dX}{dt} \tag{14}$$

The speed of the first drying phase taken equal to the drying speed value at point Xr = 1:

$$\left(-\frac{dX}{dt}\right)_0 \tag{15}$$

Xr is the reduced water content defined by [17]:

$$\begin{cases} Xr = \dfrac{X - X_{eq}}{X_0 - X_{eq}} \approx \dfrac{X}{X_0} \\ X_0 = X_{cr} \end{cases} \tag{16}$$

The coefficients of a polynomial function of degree 4 fitted to the experimental points are determined according to the following relation:

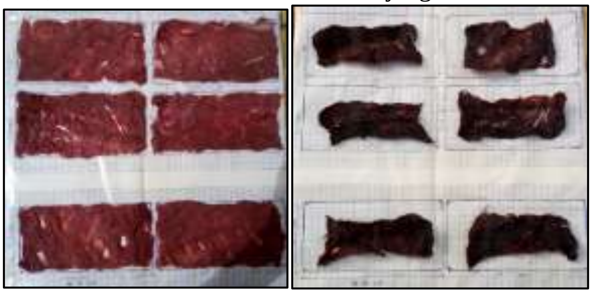
$$C_i = \frac{1}{n}\sum_{j}^{n} C_{ij} \qquad 0 \leq C_i \leq 4 \tag{17}$$

With n representing the number of tests performed, j the test number and C_i the coefficients of the functions f (Xr).

III. RESULTS AND DISCUSSION

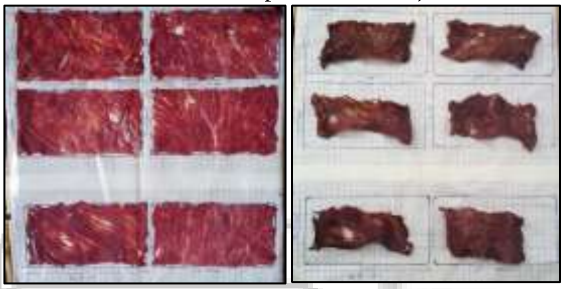
A. Experimental Results

The figures (Fig. 2, Fig. 3, and Fig. 3) show, respectively, for each experimental test the six samples of relatively equal surface, at the start and at the end of drying.



a b

Fig. 2: Samples from the 16-06-2020 test (a: samples at the start, b: samples at the end)



a b

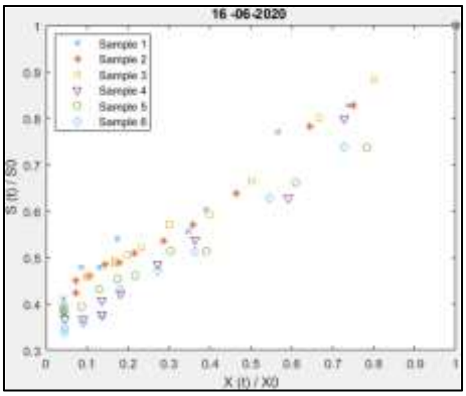
Fig. 3: Samples from the 25-06-2020 test (a: samples at the start, b: samples at the end)

a b

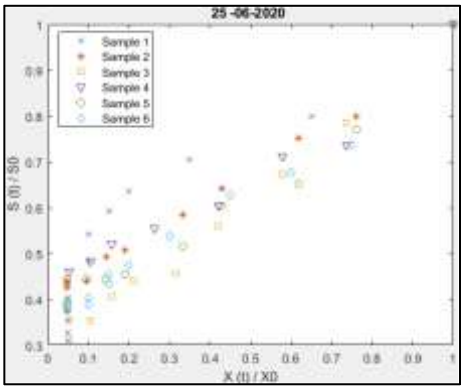
Fig. 4: Samples from the 07-07-2020 test (a: samples at the start, b: samples at the end)

1) Experimental product surface shrinkage curves

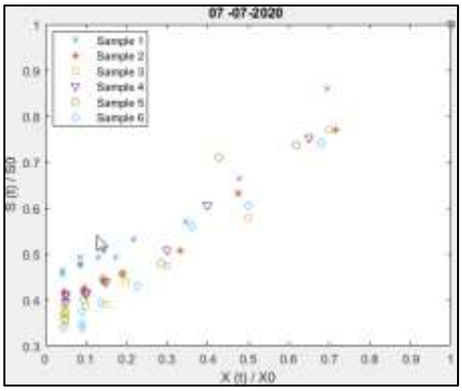
The figures below respectively show the curves of the surface shrinkage of the six samples respectively for each experimental test.



a



b



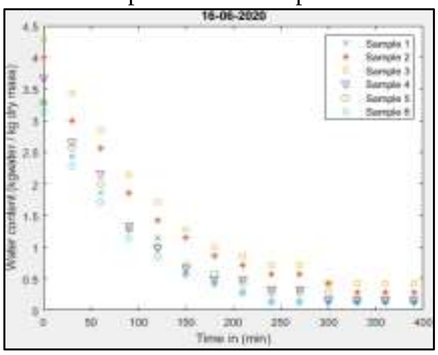
c

Fig. 5: Curve of the surface shrinkage of the samples from a, b and c test

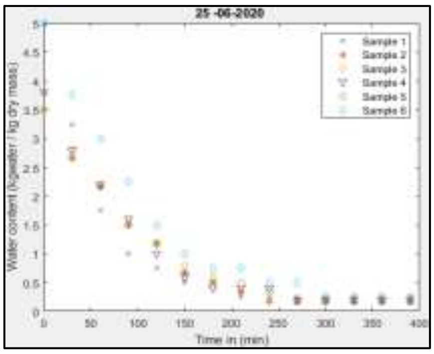
There is a linear trend for each of the surface shrinkage curves. The surface shrinkage curve that we obtained experimentally can be modeled by a linear model.

2) Experimental Curves of the Water Content of the Product

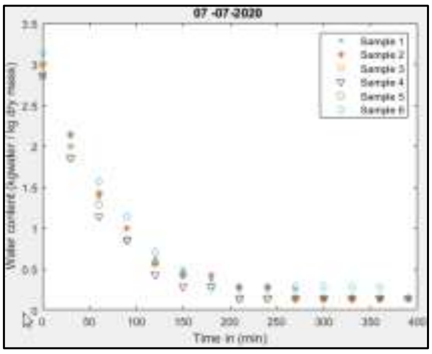
The figures below respectively show the curves of the water content of the six samples for each experimental test.



a



b



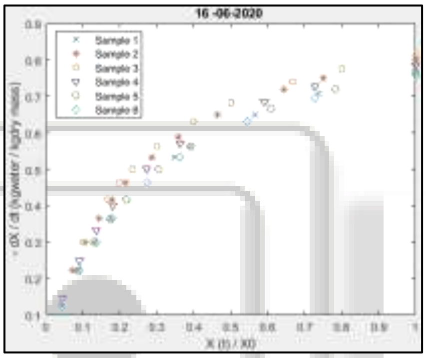
c

Fig. 6: Water content as a function of the time from a, b and c test

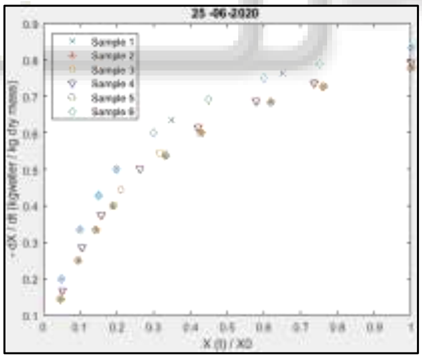
For each of the water content curves, a stability of the product is observed after six (6) hours of drying for all the samples of the various tests. The value of the water content hardly changes after this drying time.

3) Experimental Curves of Drying Kinetics

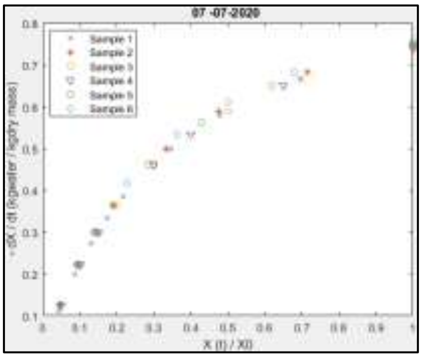
The figures below respectively show the evolution of the drying kinetics as a function of the reduced water content.



a



b



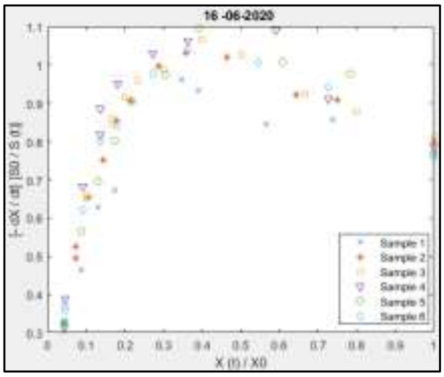
c

Fig. 7: Drying kinetics of drying samples from a, b and c test

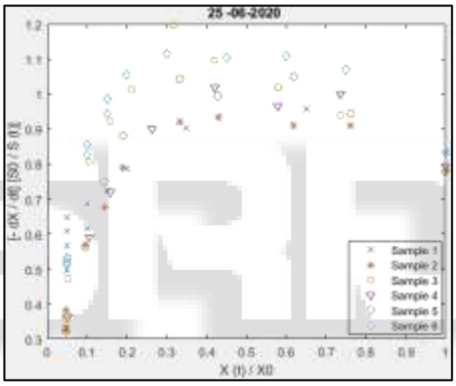
Examination of the shape of these drying curves does not allow better visibility of the constant speed drying phase. This can be corrected by taking into account the shrinkage of the product when establishing the experimental drying curves.

4) Experimental Curves of the Corrected Drying Kinetics

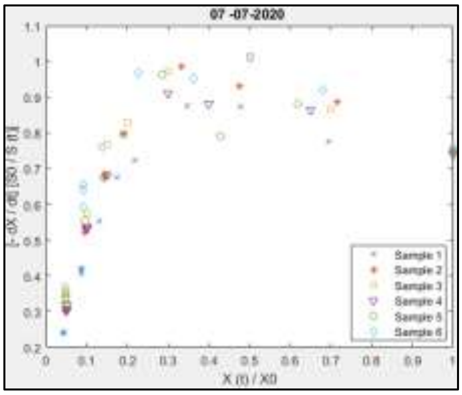
The figures below respectively show the evolution of the drying kinetics corrected according to the reduced water content; taking into account the surface shrinkage of the product



a



b



c

Fig. 8: Corrected drying drying kinetics of the samples from a, b and c test

Examination of the shape of these curves shows the different drying phases. Taking into account the surface shrinkage in establishing these curves allows us to clearly show the drying phase at constant speed as well as the point of the critical water content of the product.

B. *Results of Experimental Data Modeling*

1) *Linear Model Curve of the Surface Shrinkage of the Product*

The figure (Fig. 9) shows the curves of the surface shrinkage of the 12 samples of the slices of meat from the first two tests carried out, as well as the linear model of the surface shrinkage curve obtained with the mean values of the coefficients.

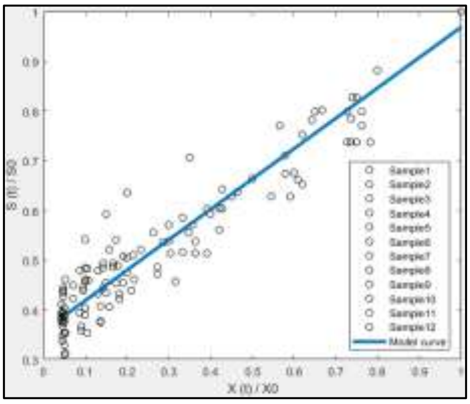


Fig. 9: Linear model of the surface shrinkage curve obtained with the 12 samples of the meat slices

We note here a weak dispersion of the experimental points around the mean curve which characterizes the linear model. The model constants determined experimentally are presented in Table 1 below.

Parameter	a	b
Value	0.611	0.357

Table 1: Parameter of the model determined experimentally

$$S_s = 0.611 + 0.357\left(\frac{X}{X_0}\right) \quad (18)$$

$$R^2 = 0.891$$

2) *Characteristic Drying Curve*

The figure (Fig. 10) shows the reduced drying speeds of the 12 samples of the slices of meat from the first two tests carried out, as well as the characteristic drying curve obtained with the mean values of the coefficients.

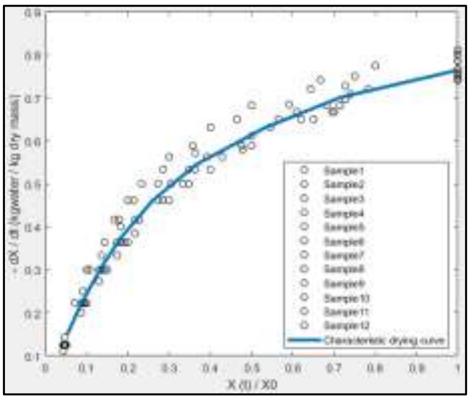


Fig. 10: Characteristic drying curve obtained with the 12 samples of the slices of meat

Table 1 below shows the values of the coefficients adopted for the adjustment polynomial of the characteristic curve.

Coefficient	C1	C2	C3	C4	C5
Value	-1.875	4.932	-5.014	2.700	0.019

Table 1: Average coefficients of the adjustment polynomial of the characteristic drying curves

$$f(Xr) = -1.875Xr^4 + 4.932Xr^3 - 5.014Xr^2 + 2.700Xr + 0.019 \quad (19)$$

$$R^2 = 0.994$$

C. *Model Validation*

The models obtained previously by modeling the experimental data on the first two tests (composed of 12 samples) are compared to the last test (composed of six samples), considered as a control. The relative errors between the two results are given by the statistical parameters calculated from the following formulas:

R-Square

$$R^2 = 1 - \frac{\frac{1}{n}\sum_{i=1}^{n}(Yexp_i - Ymod_i)^2}{\frac{1}{n}\sum_{i=1}^{n}(Yexp_i - \overline{Yexp_i})^2} \quad (20)$$

Mean Square Error

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Yexp_i - Ymod_i)^2 \quad (21)$$

Root Mean Square Error

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Yexp_i - Ymod_i)^2} \quad (22)$$

$Yexp_i$: experimental value of Y

$\overline{Yexp_i}$: mean experimental value of Y

$Ymod_i$: Model predictions value of Y

1) *Validation of the Surface Shrinkage Curve Model*

The figure (Fig. 11) shows the model of the surface shrinkage curve compared with the six samples of the control test

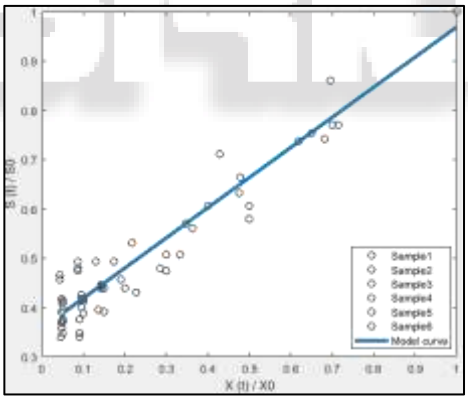


Fig. 11: Validation of the surface shrinkage curve model on the six samples of the last test

It can be seen that the data from the last test are not used for the determination of the surface shrinkage curve, dispersion of the experimental points around the linear model of the surface shrinkage curve. The table below shows the values of the statistical parameters of the relative errors between the two results.

Samples 1	R2	MSE	RMSE
Samples 2	0.8893	0.0029	0.0536
Samples 3	0.9231	0.0022	0.0465
Samples 4	0.8459	0.0054	0.0735
Samples 5	0.8983	0.0030	0.0547
Samples 6	0.9143	0.0030	0.0546

Table 3: Statistical parameters

Examination of these values shows R2 close to 1 and MSE and RMSE are low values close to 0. We can conclude that the model is satisfactory

2) Validation of the Drying Characteristic Curve Model

The figure (Fig. 12) shows the model of the drying characteristic curve compared with the six samples of the control test

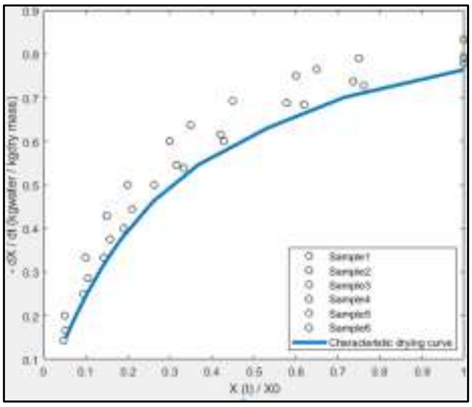


Fig. 12: Validation of the drying characteristic curve model on the six samples of the last test

It can be seen that the data from the last test are not used for the determination of the characteristic curve, a singularity of the experimental points with the characteristic curve model. The table below shows the values of the statistical parameters of the relative errors between the two results.

Samples 1	R2	MSE	RMSE
Samples 2	0.9641	0.0017	0.0414
Samples 3	0.9705	0.0017	0.0411
Samples 4	0.9588	0.0022	0.0473
Samples 5	0.9708	0.0015	0.0386
Samples 6	0.9639	0.0019	0.0439

Table 4: Statistical parameters

Examination of these values shows R2 close to 1 and MSE and RMSE are low values close to 0. We can conclude that the model is satisfactory

IV. Conclusion

In this work, the surface shrinkage curve and the drying kinetics were studied, modeled and validated with a control experimental test. Taking into account the surface shrinkage of the product, the drying kinetics curve has also been corrected in order to obtain different drying phases. The polynomial model of the drying characteristic curve and the linear model of the surface shrinkage curve of the product presented satisfactory results with the values obtained of R2 close to 1 and MSE and RMSE values close to 0.

Acknowledgment

I address my heartfelt thanks to Dr MAMAN SANI Laouali (Lecturer at Abdou Moumouni University, in charge of the Water and Environment Materials Laboratory of the Faculty of Science and Technology, Abdou Moumouni University), for allowing the access to Laboratory equipments.

I would like to thank M ADA ALMOU Mahamane (producer of kilishi at Terrain Musulman in Niamey-Niger) for his advice and his help in the preparation of thin slices of meat in the form of kilishi.

References

[1] Alfa Oumar Dissa. Séchage convectif de la mangue : Analyse de L'influence des paramètres aérauliques et intrinsèques, conception et modélisation du fonctionnement d'un séchoir solaire indirect, *Thèse Unique de l'université de Ouagadougou*, Burkina Faso, 2007.

[2] Lozano, J. E., Rotstein, E., & Urbicain, M. J. Total Porosity and Open-Pore Porosity in the Drying of Fruits, *Journal of Food Science*, Vol.45. 1980.

[3] Suzuki, K., Kubota, K., Hasegawa, T., Hosaka, H. Shrinkage in the Hydratation of Vegetables Root, *Journal of Food Science*, Vol.41, pp.1189-1193, 1976.

[4] Javier Telis-Romeo, GABAS, A. L., & PAULO, J.A.S., Osmo-Convective Drying of Mango Cubes in Fluidized Bed and Tray Dryer, *In Proceedings of the 14th International Drying Symposium*, Vol.C, pp.1868-1875, São Paulo, Brazil, 22-25 August 2004.

[5] Al-Muthtaseb, A. H., Mc Minn, W. A. M., & Magee, T. R. A. Shrinkage, Density and Porosity Variation during the Convective Drying of Patatoes Starch Gel. *14th IDS*, Vol.C, pp.1604-1611, São Paulo, Brazil, 22-25 August 2004.

[6] Hatamipour, M.S., & Mowla, D. Shrinkage of carrots during drying in an inert medium fluidized bed, *Journal of Food Engineering*, 55, 247–252. 2002.

[7] Ratti, C. Shrinkage during drying of foodstuffs, *Journal of Food Engineering*, 23(1), 91–105. 1994.

[8] Alfa Oumar Dissa, Eloi Tiendrebeogo, Salifou Garba, Jean Koulidiati. Modélisation et simulation du séchage solaire en couche mince de la Spiruline (Asthrospira platensis), *journal de la Société Ouest-Africaine de Chimie J. Soc. Ouest-Afr. Chim*. 042 : 1 – 7 21èmeAnnée, Décembre 2016

[9] Ahmat TOM. Contribution au séchage solaire des produits carnés: modélisation et réalisation d'un séchoir adapté aux pays tropicaux, *Thèse de doctorat, École Nationale Supérieure d'Arts et Métiers, ParisTech* France 2015

[10] Kilpatrick, P. W., Lowe, E., & Van Ardsel, W. B. Tunnel dehydrators for fruit and vegetables. In E. M. Mrak, & G. F.Stewart (Eds.), *Advances in food research* (vol. 6, pp. 313–372). New York: Academic Press. 1955.

[11] Desmorieux, H. Le Séchage en Zone Subsaharienne: Une analyse Technique à Partir des Réalités Géographiques et Humaines, *Thèse présentée à l'INPL, Loraine*, France. 1992.

[12] Iglesias, O., Garcia, A., Roques, M., & Bueno, J. L. Drying of water gels: Determination of the characteristic curve agar-agar. *Drying technology*, 3, 11, 571- 587. 1993.

[13] Leonardo Da, S.A. & Dermeval, J. M. S., Dependence Analysis of Shrinkage and shape evolution of a gel System With the Forced Convection Drying Periods, *In Proceedings of the 14th International Drying*

Symposium, Vol.A, pp.152-160, São Paulo, Brazil, 22-25 August 2004.
[14] D.A. Van Meel. Adiabatic convection batch drying with recirculation of air, *Chemical Engineering Science*, vol. 9, pp.36-44, 1958.
[15] A. Khouya et A. Draoui. Détermination des courbes caractéristiques de séchage de trois espèces de bois. *Revue des Energies Renouvelables* Vol. 12 N°1 (2009) 87 – 98
[16] A. Khouya. 'Contribution aux Etudes Expérimentale et Numérique d'un Processus de Séchage du Bois', *Thèse de Doctorat, Université Abdelmalek Essaâdi, FST de Tanger*, Maroc. 2008
[17] Haoua AMADOU. Modélisation du séchage solaire sous serre des boues de stations d'épuration urbaines, *Thèse de doctorat en Sciences pour l'ingénieur. Université Louis Pasteur-Strasbourg I : École doctorale MSII*, 248p. 2007.
[18] A. Belghit, M. Kouhila, B.C. Boutaleb, Experimental study of drying kinetics by forced convection of aromatic plants, *Energy Conversion and Management*,44(12), Pages 1303-1321, 2000.
[19] S. Ben Mabrouk, A. Belghith. Simulation and design of a tunnel dryer. *Renewable Energy Int. Journal*, 5(1), 469 – 473, 1994.
[20] S. Lahsasni, M. Kouhila, M. Mahrouz, A. Idlimam, et A. Jamali, Thin layer convective solar drying and mathematical modeling of prickly pear peel, *Energy 29*, Pages 211 – 244, 2004.
[21] L. Ait Mohamed, C.S. Ethmane Kane, M. Kouhila, A. Jamali, M. Mahrouz, N. Kechaou, Thin layer modelling of Gelidium sesquipedale solar drying process. *Energy Conversion and Management* 49, pp 940-946, 2008.
[22] B. Khiari, S. Ben Mabrouk, M. Sassi. Modelling of heat and mass transfer in a tunnel dryer. *Applied Thermal Engineering*, 26, 2110 – 2118; 2006.
[23] S. Ben Mabrouk, El. Benali, H. Oueslati. "Experimental study and numerical modelling of drying characteristics of apple slices". *Journal of Food and Bioproducts Processing*. FBP_301, Junuary 2012.
[24] A. Touil, S. Chemkhi, F.Zagrouba, Modelling of the Drying Kinetics of Opuntia Ficus Indica Fruits and Cladodes. *International Journal of Food Engineering* 6 (2), Article 11, 2010